

Recent Spin Results from PHENIX



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PHENIX Collaboration

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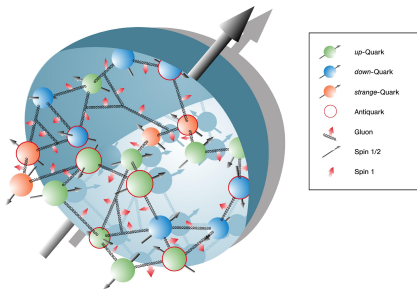
Nucleon Spin Structure

Spin Decomposition

$$\langle S_z \rangle = \frac{1}{2} = \frac{1}{2} \Delta \Sigma + \Delta G + L_q + L_g$$

The overall spin of the proton must derive from:

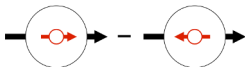
- $\Delta \Sigma$: valence/sea quark polarization ~ 0.3 from pDIS
- ΔG : gluon polarization
- L_q : Quark/antiquark orbital angular momentum
- L_g : Gluon orbital angular momentum



Polarized Parton Distribution Functions

Spin Dependence

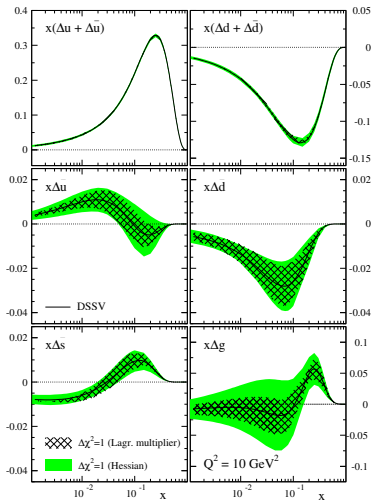
$$\Delta f_q(x, Q^2) = f_{q+}(x, Q^2) - f_{q-}(x, Q^2)$$



Experimental Determination

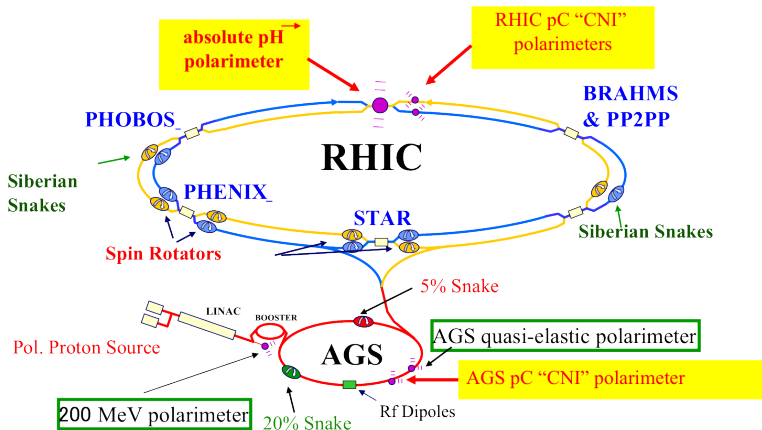
- Polarized DIS accesses $\Delta q + \Delta \bar{q}$ distributions with high precision
- Separating contributions from valence and sea quarks requires additional hadron in final state (SIDIS)
- Large uncertainty in fragmentation functions leads to large uncertainty on sea quark polarization
- Gluon polarization is largely unconstrained

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RHIC

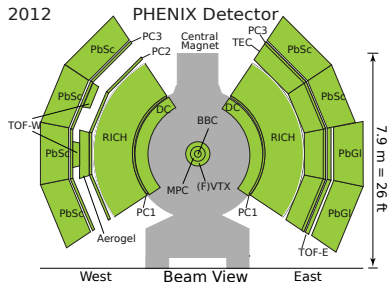
Brookhaven National Laboratory
World's only polarized pp collider



Up to $\sqrt{s} = 510$ GeV with $P \sim 60\%$ in transverse or longitudinal orientation

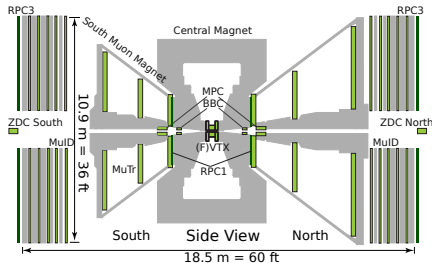
PHENIX Central Arm

2012



- Energy measured in EM Calorimeter (PbSc + PbGI)
- Momentum/Tracking in Drift Chamber (DC) + Silicon Barrel (VTX)
- PID with Ring Imaging Cherenkov Counter (RICH)
- $|\eta| < 0.35$, $\Delta\phi = 2 \times \frac{\pi}{2}$

Forward Muon Spectrometer



- Silicon strip tracking and vertexing (FVTX)
- Momentum measured in cathode strip tracking chambers (MuTr)
- μ^\pm ID from larocci tubes interleaved with steel absorbers (MuID)
- $1.2 < |\eta| < 2.2$, $\Delta\phi = 2\pi$

RHIC Spin

Recent Runs

Recent Spin Runs

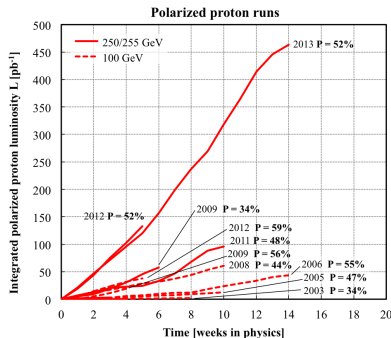
- 2009: First 500 GeV longitudinal
- 2011: 500 GeV longitudinal
- 2012: 200 GeV transverse and 510 GeV longitudinal
- 2013: 510 GeV longitudinal run

Combined data from 2009-2013 longitudinal runs provide a high statistics, high polarization sample for sea quark and gluon polarization studies

Figures of Merit

- Single Spin Asymmetry FOM: $L\langle P \rangle^2$
- Double Spin Asymmetry FOM: $L\langle P \rangle^4$

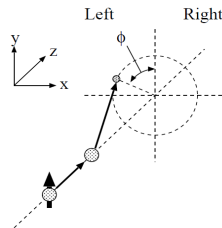
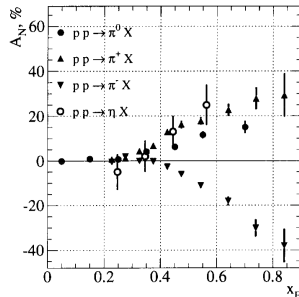
High polarization is essential for an effective measurement of A_{LL}



Transverse Spin

Unexpected Results

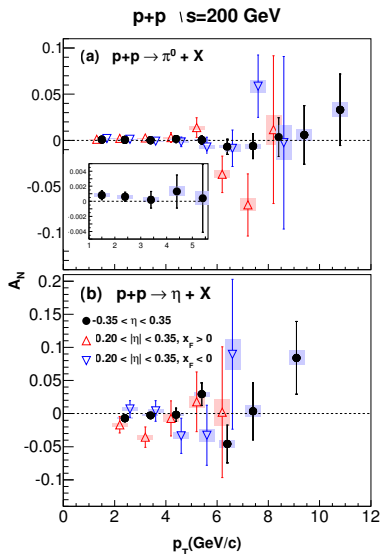
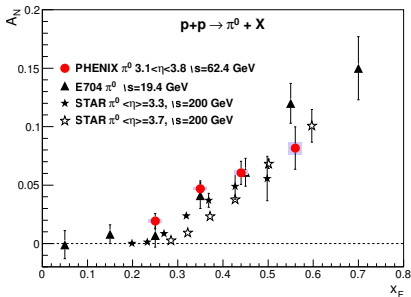
- Collinear pQCD has small spin dependence, i.e. no asymmetry
- Large forward A_N has been observed since E704 (1998)
- Still remains unexplained
- Recently, thanks to RHIC, there has been a large theoretical and experimental effort



$$A_N = \frac{1}{P} \frac{N_L^\uparrow - N_R^\uparrow}{N_L^\uparrow + N_R^\uparrow}$$

Neutral Meson A_N (arXiv:1312.1995)

- π^0, η studied in both forward and central EM calorimeter at both 200 GeV and 62.4 GeV
- Sizable asymmetry seen at forward rapidity
- Consistent with zero at central rapidity with unprecedented accuracy



Gluon Polarization

Experimental Accessibility

Double Longitudinal Spin Asymmetry

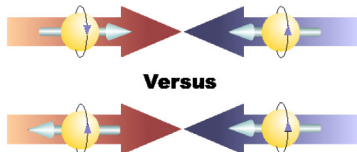
$$A_{LL} = \frac{\sigma_{++} - \sigma_{+-}}{\sigma_{++} + \sigma_{+-}} = \frac{\sum_{a,b,c=q,\bar{q},g} \Delta f_a \otimes \Delta f_b \otimes \Delta \hat{\sigma} \otimes D_{h/c}}{\sum_{a,b,c=q,\bar{q},g} f_a \otimes f_b \otimes \hat{\sigma} \otimes D_{h/c}}$$

or in terms of particle yield

$$A_{LL} = \frac{1}{P_B P_Y} \frac{N_{++} - R N_{+-}}{N_{++} + N_{+-}}$$

where P_X is the polarization of beam X and R is the relative luminosity

$$R = \frac{L_{++}}{L_{+-}}$$

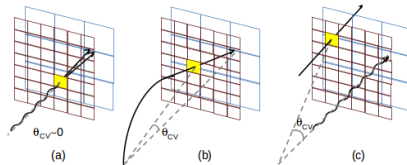


Sensitivity of A_{LL} to helicity PDFs depends on the selected probe as well as the dominant production mechanisms at a given \sqrt{s} (i.e. qg scattering, gg fusion)

π^0 A_{LL} Analysis

π^0 ID

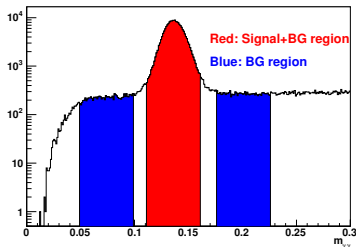
- Trigger on high energy photon
- Remove background using EM shower shape, ToF, charge veto
- Can eliminate charged hadronic background, conversion background remains



Asymmetry Extraction

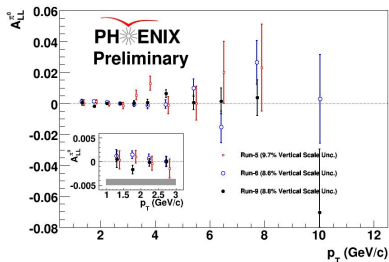
- Divide into background and signal mass regions
- Measure inclusive A_{LL} under the mass peak
- Estimate BG asymmetry using sidebands on either side of π^0 peak

$$A_{LL}^{\pi^0} = \frac{A_{LL}^{\pi^0+BG} - r A_{LL}^{BG}}{1 - r}, \quad r = \frac{N_{BG}}{N_{BG} + N_{\pi^0}}$$

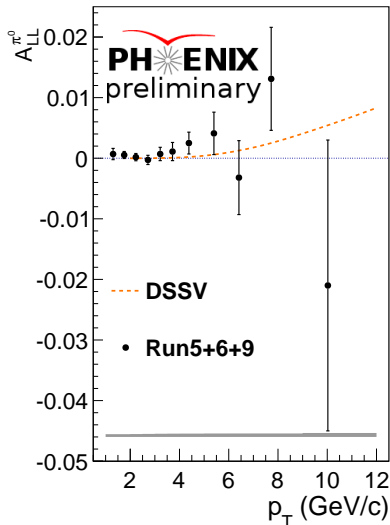


π^0 A_{LL}

Results

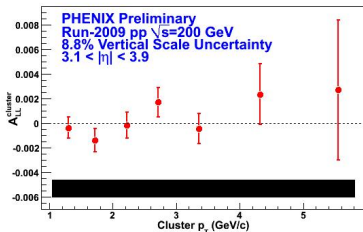
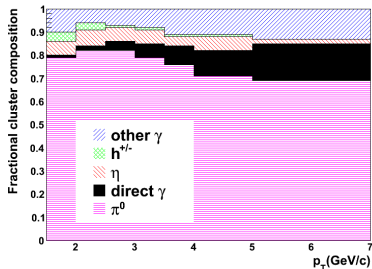
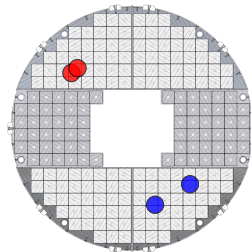


- Favors a larger asymmetry than predicted by DSSV
- Relative luminosity is a significant systematic uncertainty, improved understanding could provide significant benefit to current results
- Submitting for publication in Phys. Rev. D this week



Forward Cluster A_{LL}

- Forward EM Calorimeter (MPC) at $3.0 < |\eta| < 3.8$
- $\gamma\gamma$ from **high energy** π^0 merge into clusters
- Clusters are estimated to be $\geq 80\%$ π^0 by simulation
- Run 13 statistical uncertainties will be $\mathcal{O}(10^{-4})$ and reach $x \sim 10^{-3}$

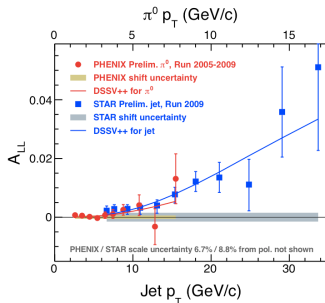


Recent Results

ΔG

First Signs of Non-Zero ΔG

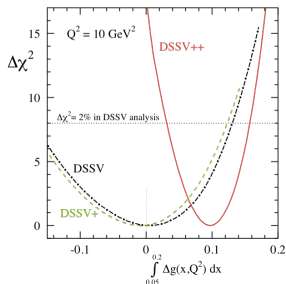
- PHENIX π^0 data from 2005-2009
- STAR jet data from 2009
- Preliminary results in RHIC Spin write up arXiv:1304.0079



Truncated Integral

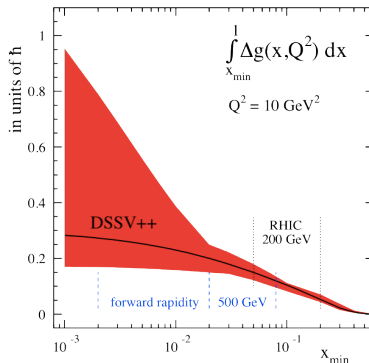
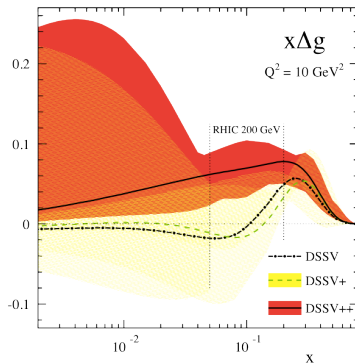
- Included in new global fits (DSSV++) that suggest a non-zero gluon polarization in probed x range

$$\int_{0.05}^{0.2} \Delta g(x) dx = 0.1 \pm_{0.07}^{0.06}$$



Recent Results

Global Fit: DSSV++



Outlook

- Large uncertainties remain in both the shape and integral of $\Delta g(x)$
- Unconstrained in the low x range where currently no data is available
- Improvements forthcoming from A_{LL} measurements at 510 GeV and forward rapidity

Sea Quark Polarization

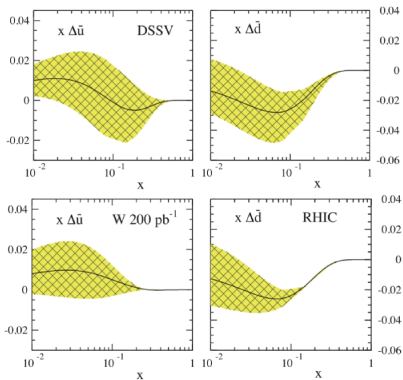
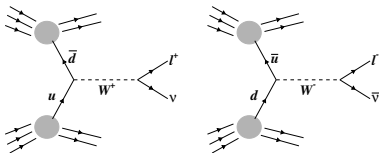
W Program

The W single spin asymmetry

$$A_L^W = \frac{1}{P} \frac{N_+ - N_-}{N_+ + N_-}$$

has a direct connection to helicity PDFs

$$A_L^{W^+} = - \frac{\Delta u(x_1) \bar{d}(x_2) - \Delta \bar{d}(x_1) u(x_2)}{u(x_1) \bar{d}(x_2) + \bar{d}(x_1) u(x_2)}$$

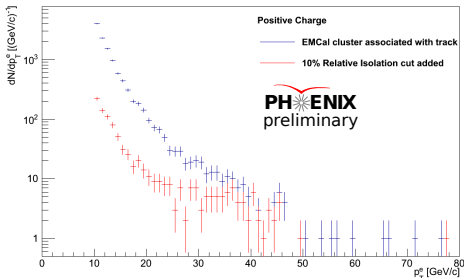
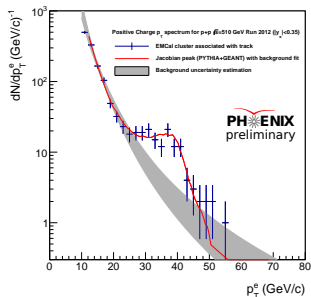
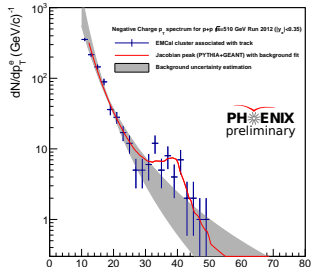


Projected RHIC impact on sea quark helicity PDFs with 200 pb^{-1} of longitudinal pp collisions at $\sqrt{s} = 500 \text{ GeV}$

Central Arm W Analysis

Analysis Details

- Jacobian peak at $p_T \sim m_W/2$ in $e^\pm p_T$
- Background estimated with a power law
- Simulated signal peak
- Background rejection via relative isolation cut
- **Improvements in background estimation in progress**

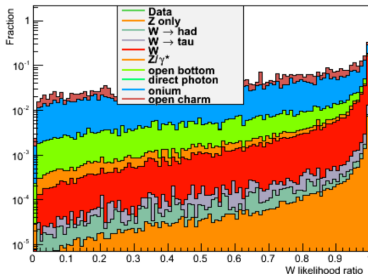


Muon Arm W Analysis

Challenges

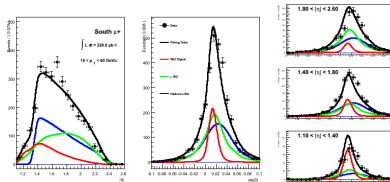
- Highly suppressed/no jacobian peak at forward rapidity
- Large single muon backgrounds: $S/B < 1$
- Fake high p_T muons from hadronic decay-in-flight

South arm μ^+ candidates



Method

- Simulation driven multivariate cut using likelihood ratio for event selection
- S/B ratio estimation: unbinned maximum likelihood fit



Combined Results

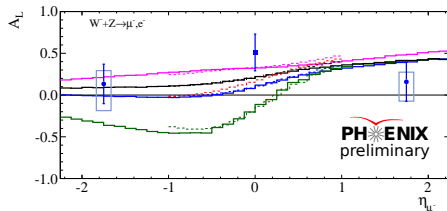
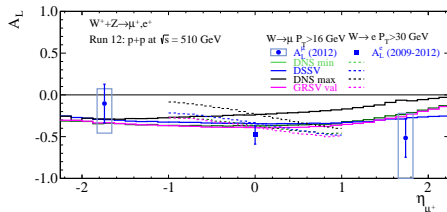
2009-2012

Included Results

- Central $W^\pm \rightarrow e^\pm \nu_e$ combined results from Runs 9-12
- Forward $W^\pm \rightarrow \mu^\pm \nu_\mu$ from Run 12

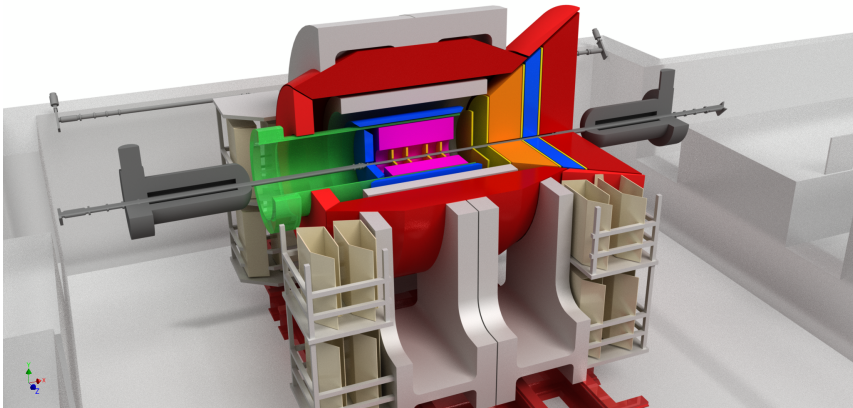
Outlook

- Run 13 analysis is nearing completion
- Higher statistics data set allows for better control of errors and η dependence
- Previous measurements continuing to improve



sPHENIX/ePHENIX

Proposed upgrade path for PHENIX to a future EIC at RHIC



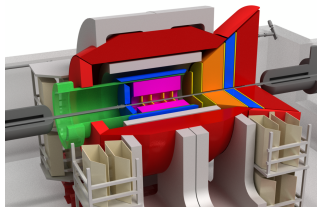
arXiv:1402.1209

sPHENIX/ePHENIX

Optimized for jets, photons, and DY over a large rapidity range ($1 < \eta < 4$)

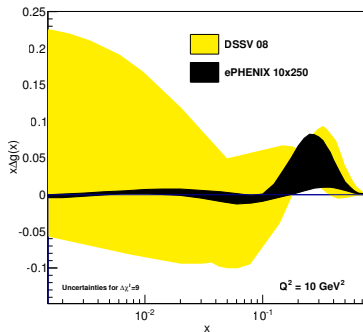
Design

- Built around the BaBar solenoid
- GEM based tracking
- RICH based PID
- EM and hadronic calorimetry
- Muon identification



Capabilities

- Low x reach for a definitive constraint on ΔG
- Strange sea quark polarization through K asymmetries
- Transverse Momentum Distributions (TMDs) over a wide x range



Conclusion

Summary

- PHENIX measures a variety of probes that access complementary aspects of the nucleon spin structure
- First indication of a possible non-zero gluon polarization has been seen at RHIC
- First measurements for constraint of the sea quark polarization have been completed

Outlook

- A large statistics longitudinal data set has been collected in Run 13 and numerous analyses are currently under way
- Recorded data will allow further constraints to be placed on both the gluon polarization and the polarized sea quark distributions in the near future
- Transverse spin run planned for 2015 with pA
- e/sPHENIX upgrade currently under R&D and planning for precision measurement of gluon polarization, strange quark polarization, and transverse spin phenomena

Backup

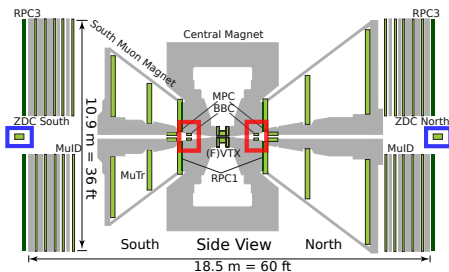
Experimental Challenges

Relative Luminosity

- Two nominally minimum bias, low noise detectors are used for luminosity monitoring
- Systematic uncertainty given by discrepancy in RL as seen by the two detectors

Outlook

- Going forward, high statistics measurements will be systematics limited by RL
- Systematic has historically *increased*
- In Run 13 FVTX was modified to serve as a third detector to better understand the discrepancy



Run (\sqrt{s})	$\delta A_{LL}(\text{sys})$
2005 (200 GeV)	2.5×10^{-4}
2006 (200 GeV)	7.5×10^{-4}
2009 (200 GeV)	13×10^{-4}